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VacciCost – A tool to estimate the resource requirements for implementing livestock vaccination campaigns. Application to peste des petits ruminants (PPR) vaccination in Senegal

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ABSTRACT

Vaccination is one of the main tools currently available to control animal diseases. In eradication campaigns, vaccination plays a crucial role by reducing the number of susceptible hosts with the ultimate goal of interrupting disease transmission. Nevertheless, mass vaccination campaigns may be very expensive and in some cases unprofitable. VacciCost is a tool designed to help decision-makers in the estimation of the resources required to implement mass livestock vaccination campaigns against regulated diseases. The tool focuses on the operational or running costs of the campaign, so acquisition of new equipment or vehicles is not considered. It takes into account different types of production systems to differentiate the vaccination productivity (number of animals vaccinated per day) in systems where animals are concentrated and easy to reach, from those characterized by small herds that are scattered and less accessible. The resource requirements are classified in eight categories: vaccines, injection supplies, personnel, transport, maintenance and overhead, training, social mobilization, and surveillance and monitoring. This categorization allows identifying the most expensive components of a vaccination campaign, which is crucial to design cost-reduction strategies. The use of the tool is illustrated using data collected in collaboration with Senegalese Veterinary Services regarding vaccination against peste des petits ruminants. The average daily number of animals vaccinated per vaccination team was found to be crucial for the costs of the campaign so significant savings can be obtained by implementing training to improve the performance of vaccination teams.

1. Introduction

Animal vaccination is usually considered as a cost-effective method to prevent animal disease, enhance the efficiency of food production, and protect human health by reducing the risk of transmission of zoonotic and foodborne pathogens from animals to people (Roth, 2011; Shimshony and Economides, 2006). The role of vaccination has been crucial in eradicating rinderpest, the first animal disease to be eradicated globally (Mariner et al., 2012). Also, vaccination can greatly reduce the potential of major epidemics (Keeling et al., 2002).

High-risk countries, i.e. disease-free countries surrounded by areas in which the disease is present, or countries importing animals from endemic areas, may use animal vaccination to protect their national stock since other strategies such as surveillance associated with stamping-out can be too costly and disruptive (Horst et al., 1999; Shimshony and Economides, 2006). To be successful, vaccination coverage has to be high enough to decrease the number of susceptible animals to sufficiently low levels such that disease transmission is interrupted (Woolhouse et al., 1996).

Moreover, veterinary vaccines are of particular interest in the context of growing concerns related to antimicrobial resistance as they contribute in some cases to decreased use of antibiotics by preventing infections in food producing and companion animals (Roth,

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2011). In the case of livestock, when vaccination is considered as a public health policy, funded by public resources, considering its cost is crucial to properly evaluate its effectiveness and ensure a favorable cost-benefit ratio.

1.1. Rationale of a tool like VacciCost

National authorities frequently have to allocate resources to reach the socially–as well as epidemiologically, optimal vaccination coverage due to the positive externalities (benefits generated by an activity that are experienced by unrelated third parties) associated with vaccinating (McLeod and Rushton, 2007).

A possible strategy to eliminate a disease from an infected area and to stop the transmission of the causative pathogen agent is to implement successive annual mass vaccination campaigns. The goal is to vaccinate over a short period of time a very high proportion of the target population, defined as the subset of the general susceptible and immunologically competent population (i.e. at risk of infection and able to produce an immune response after vaccine administration).

To properly and objectively analyze the possibility of implementing mass vaccination campaigns financed or co-financed by public funds, national authorities and funding agencies need accurate estimates of the vaccination cost. A tool providing such estimates is useful for several reasons:

ex-ante assessment of the viability and cost-effectiveness of a mass vaccination campaign;

assistance for preparing budgets, especially if the campaign involves both governmental resources and complementary financial support by international organizations;

comparison of different vaccination strategies, depending on the availability of resources and the duration of the vaccination program.

Additionally, at the individual level, the decision to vaccinate results from an empirical evaluation of the expected benefits of immunizing animals against the costs that vaccination represents for the farmers, based on the individuals' knowledge and perception of the disease risk. In some cases (disease absent from their herd and neighborhood, low prevalence, little impact...), the perceived risk of infection is not high enough to make them decide to vaccinate their herds. Therefore, if the disease spread poses a public health risk, subsidizing schemes might be necessary to encourage livestock owners to vaccinate and reach the objective in terms of immunity coverage (Gethmann et al., 2015).

1.2. Control and eradication programs

Control, and a fortiori eradication, of animal diseases from a given area generally involves a lot of resources and coordination efforts. Estimating the costs associated with disease control or eradication, including vaccination, is crucial during the planning process and for seeking adequate and sufficient funding to ensure success of the program. Underestimating the costs can lead to inappropriate implementation of vaccination hence negatively impacting the immunization coverage and giving opportunities for the pathogen to survive; on the other hand, overestimating the costs can discourage decision makers from investing in the control or eradication campaign.

This paper presents VacciCost, a tool developed to help estimating the resource requirements to implement mass livestock vaccination campaigns, as well as a case study using field data collected in Senegal on the vaccination costs for peste des petits ruminants (PPR), a major infectious viral disease of sheep and goats widespread in Africa, the Middle East, and Asia (Baron et al., 2016). A global PPR control and eradication strategy has been developed by the Food and Agriculture Organization of the United Nations (FAO) and the World Organisation for Animal Health (OIE) (OIE and FAO, 2015; Raj et al., 2015). Different scenarios are constructed to estimate the resource requirements associated with PPR vaccination.

In the following sections, the VacciCost tool is described in detail along with the data required to use it. The data collected in collaboration with Senegalese Directorate of Veterinary Services are described and scenarios reflecting different vaccination productivity levels (number of animals vaccinated per day per vaccination team) are constructed to assess the influence of some parameters on the cost evaluation. Next, results are presented and discussed, as well as the tool's limitations.

2. Methodology

2.1. VacciCost description

VacciCost was developed following the same cost structure as the World Health Organization (WHO) guidelines to construct comprehensive multiyear plans (cMYP) for human immunization programs (World Health Organization, 2006), adapting it to the livestock sector and structured for a single year period. It focuses on the operational or running costs – excluding the capital costs associated with goods that are not consumed or replaced every year such as the cold-chain equipment to store the vaccine before its use, vehicles or buildings. The tool was developed in an Excel® spreadsheet (Microsoft Corp.) and its proper functioning requires installing the open source OpenPERT Microsoft Excel 'add-in' (https://code.google.com/archive/p/openpert/).

The flexibility of the tool allows its use for estimating the cost of vaccination campaigns against any livestock disease and for livestock sectors characterized by two contrasted farming systems with structural differences that affect the ease with which livestock are reached: production systems where animals are reared in small flocks ("backyard" or "mixed crop-livestock" systems) *versus* production systems where animals are reared in bigger herds ("industrial" or "pastoral" systems). Resource requirements are estimated taking as input the availability of human resources (in number of vaccination teams) and returning the length of the vaccination campaign (in days), or *vice versa*. Fixed costs, including capital depreciation (vehicles, buildings, *etc.*), are not included in this tool. If the objective is to estimate the total cost of vaccination (operational and fixed costs), the results of VacciCost need to be complemented to capture the fixed component.

2.2. Cost components

The resource requirements are computed according to the following components: vaccines, injection supplies, staff, transport, maintenance and overhead, training, social mobilization, and surveillance and monitoring. Additional incentives to increase the farmers' willingness to vaccinate (such as monetary incentives or free deworming while vaccinating) can be considered when needed. Table 1 summarizes the data required as input for each component.

The productivity of vaccination teams is a crucial parameter for the cost estimation. However, it is not easy to estimate. To account for its uncertainty, productivity of vaccination teams is considered as a random variable described by a PERT distribution. The parameters of such distribution are the minimum, maximum, and the most likely value; a 95% confidence interval can be computed around the average cost.

Vaccinating small flocks (i.e. backyard production or smallholder mixed crop-livestock systems in developing countries) is associated with lower productivity of vaccination teams – mea-

Table 1
Input data for VacciCost.

Category	Data required	
Population & vaccination coverage	- Livestock population (number of animals) - Livestock population by production system	- Coverage target (%)
1. Vaccines	- Number of doses per animal - Price per dose (USD)	- Freight & handling charges (as % of market price) - Wastage rate (%)
2. Injection supplies	- Cost of injection supplies per dose (USD) - Freight & handling charges (USD)	- Wastage rate (%)
3. Personnel	- Composition of a vaccination team (number of vets, drivers, supporting staff) - Wages per hour (USD) - Number of daily working hours	- Length of campaign (months) Or number of teams available - Team productivity (number of animals vaccinated) each day per team) - Monthly perdiems and financial incentives (USD)
4. Transport	- Number of vehicles per team - Average distance per day (km) - Vehicles' fuel efficiency (km/liter)	- Average fuel price (USD/Liter) - Cost of maintenance (% of fuel consumption) - Other transportation expenses per team (USD)
5. Maintenance & overhead	- Number and cost of cold chain equipment per team (units & USD) - Cost of maintenance (% of equipment value)	- Other monthly overheads (electricity bills, etc.) (USD)
6. Training	- Hourly cost of training per person (USD)	- Number of hours of training required per agent
7. Social mobilization	- Cost of social mobilization activities per team (USD)	- Cost of incentives provided to farmers (USD/vaccinated animal)
8. Surveillance & monitoring	- Unit cost of seroprevalence test (USD) - Number of teams supervised per monitor - Monthly wage of monitor (USD)	- Number of months worked by a monitor - Disease prevalence to be detected - Confidence level for sample size calculation

sured by the average number of animals vaccinated per team per day. As a matter of fact, in these systems, it is often difficult to gather the animals from many small herds. Also, there is a lack of infrastructures such as vaccination pens. Conversely, in pastoral and agro pastoral systems, where animals are kept in larger flocks, the productivity of vaccination teams is usually much higher. Therefore, a percentage reduction in the productivity of vaccination teams working in production systems with small flocks is considered. Moreover, when considering small ruminants (sheep and goats) reared in mixed crop-livestock systems of sub-humid regions, the births are homogeneously distributed all over the year and birth rate is higher than in drier environment thanks to better forage resources. Therefore, with such a high population turnover, two vaccination campaigns must be implemented each year to maintain high immunity coverage in the small ruminant population.

Injection supplies include needles, syringes, safety boxes, gloves, *etc*. The number of vaccines and injection supplies are estimated based on the livestock population, the number of doses required per animal, and the coverage target of the vaccination program. Then, the productivity of vaccination teams is randomly generated and used to estimate the number of teams required to implement the vaccination campaign (or the length of the vaccination campaign, in case the number of teams is fixed). Along with the rest of the inputs, the number of vaccination teams is used to estimate the remaining cost components in a deterministic way. This procedure is repeated 300 times (i.e. 300 draws of vaccination teams' productivity) so mean values and confidence intervals can be constructed. Details on the procedure to calculate the resource requirements can be found in the Supplementary material S1 (User's manual).

VacciCost automatically computes the costs and generates a report that summarizes within a single sheet the main results for each component with a graph, a pie chart, and tables. This allows easy identification of the main sources of costs in a vaccination campaign as well as the most expensive components of the vaccination strategy being evaluated, and facilitates the design of strategies seeking for further savings.

2.3. Data collected from Senegal

In collaboration with the National Directorate of Veterinary Services (DVS), we analyzed the weekly reports corresponding to the 2012–2013 livestock vaccination campaign. The information available was not completely exhaustive and/or detailed, so it was complemented using data from the report of the DCI-Food EU-funded activity "Vaccines for the Control of Neglected Animal Diseases in Africa" (VACNADA), a project implemented during the 2010-2011 vaccination campaign in the northern region of Saint-Louis with the objective of increasing the vaccination coverage against PPR.

The distribution of the small ruminant population according to the farming systems was estimated using the database Gridded Livestock of the World (Robinson et al., 2014). Some information, such as staff wages, vaccine cost and small ruminant market prices, was obtained during a workshop organized in October 2015 in Dakar and completed with requests addressed to the Senegalese Institute for Agricultural Research (ISRA), which produces and sells the PPR vaccine. Finally, officials of the DVS, as well as some private veterinarians who have an official mandate to implement PPR vaccination on behalf of DVS were consulted to obtain data on the productivity of vaccination teams. Collected data are summarized in Table 2.

We assumed that vaccination teams worked during eight months while post-vaccination evaluation teams, whose structure is the same as vaccination teams (see Table 2), worked only during the last 2 months to assess the effectiveness of the PPR vaccination campaign.

Several difficulties were met while estimating the productivity of vaccination teams. Firstly, in Senegal, 70% of the vaccination activities are delegated to private veterinarians. They are supposed to report their advances in the vaccination campaign; however, some inconsistencies were found regarding the frequency of reporting (delayed and missing reports) leading to difficulties to compute the level of vaccination productivity. Secondly, animal immunization campaigns cover four diseases and several

Table 2
Data collected in Senegal (costs in CFA Franc (XOF)).

Variable	Value	Source
Exchange rate (USD/XOF)	0.0017	XE.com (value at the end of 2015)
Animal population		
By Production system		
Pastoral	8,919,581	Gridded Livestock of the World (Robinson et al., 2014)
Mixed crop-livestock	1,355,724	Gridded Livestock of the World (Robinson et al., 2014)
By Age group		
Adults (>3 months)	85%	Workshop with Veterinary Services
Young (<3 months)	15%	Workshop with Veterinary Services
Vaccines		
No. vaccination campaigns in pastoral system	1	Workshop with Veterinary Services
No. vaccination campaigns in mixed system	2	Workshop with Veterinary Services
Price per dose	30	Workshop with Veterinary Services
Cost of injection supplies (per dose)	32	Workshop with Veterinary Services
Freight and handling charges	15%	WHO's cMYP guidelines
Wastage	10%	WHO's cMYP guidelines
Personnel		
Composition of teams		
Vets	0.5	Workshop with Veterinary Services
Livestock technicians/Assistants	2	Workshop with Veterinary Services
Others	0.5	Workshop with Veterinary Services
Average monthly wages of:		
Vets	355,000	Workshop with Veterinary Services
Livestock technicians/Assistants	200,000	Workshop with Veterinary Services
Others	80,000	Workshop with Veterinary Services
Hours worked per day	8	Workshop with Veterinary Services
Monthly per diems	0	Workshop with Veterinary Services
Transport		
Number of vehicles per team	0.25	Workshop with Veterinary Services
Average distance traveled per day (km)	100	Workshop with Veterinary Services
Fuel efficiency of vehicles (km/l)	11	Workshop with Veterinary Services
Fuel price per liter	790	Workshop with Veterinary Services
Maintenance of vehicles (% fuel used)	15%	WHO's cMYP guidelines
Other transportation expenses (per team)	60,500	Workshop with Veterinary Services
Maintenance & Overheads		
Number of small boxes per team	1	Workshop with Veterinary Services
Number of big boxes	110	Workshop with Veterinary Services
Price of small boxes	30,211	Senegal's cMYP
Price of big boxes	1,812,689	Senegal's cMYP
Maintenance cost (as % of value)	5%	WHO's cMYP guidelines
Training		
Cost of 1 h of training per person	5000	Workshop with Veterinary Services
No. hours of training required per person	8	Workshop with Veterinary Services
Social mobilization		
Cost of social mobilization per team	136,000	Workshop with Veterinary Services
Surveillance & monitoring		
Unit cost of seroprevalence test	2000	Lab. Nat. d'Elevage et de Rech. Vét.
Number of teams supervised per monitor	30	Workshop with Veterinary Services
Monthly wage of monitor	250,000	Workshop with Veterinary Services
Active surveillance teams	4	Workshop with Veterinary Services
Number of months worked by surveillance team	2	Workshop with Veterinary Services
Prevalence expected to be detected	0.001	Workshop with Veterinary Services
Confidence level (sample size calculation)	95%	Workshop with Veterinary Services

species (PPR in small ruminants, lumpy skin disease in cattle, African horse sickness in horses, and Newcastle disease in poultry) which are addressed at the same time to minimize the logistic costs (transportation, cold chain, staff wages…). Consequently, the sole productivity estimates for PPR vaccination do not reflect the real capacity of the teams, whose productivity is underestimated. Thirdly, private veterinarians are given specific vaccination objectives from the DVS that depend on the financial resources available for the campaign. Hence, the targeted vaccination coverage is sometimes as low as 30% of the estimated small ruminant population. To minimize the time spent on vaccination, private veterinarians generally decide to select the animals that are the easiest to gather, leading to spuriously high productivity.

To evaluate the influence of the teams' vaccination productivity and of the percentage reduction in productivity applied to production systems with small flocks on the vaccination cost, we decided to analyze the cost of PPR vaccination using four different scenarios derived by varying the productivity and the percentage reduction applied for systems with small flocks. The first two scenarios (A and B) were characterized by a high level of vaccination productivity – using respectively the minimum (800 animals), maximum (1,500 animals), and the most likely (1000 animals) daily productivity levels reported by private veterinarians, and corresponding to their estimated productivity in production systems with large flocks (pastoral systems). Scenarios A and B differed according to the percentage reduction applied to the baseline productivity level, lower in scenario A (50%) than in scenario B (70%). Those values were chosen after consultation with the Senegalese DVS and private veterinarians. The other two scenarios (C and D) were characterized by a low productivity of vaccination teams–with respectively the minimum (100 animals), maximum (795 animals) and the most likely (316 animals) daily productivity levels as indicated in the vaccination records that were available in districts where pastoral systems are predominant. Scenario C had a 50% reduction in productivity for small flocks while for scenario D, a 70% reduction was applied.

The vaccination coverage used in the analysis was 80%, a figure which was reached in Senegal after several years of mass vaccination against rinderpest in cattle (Sarr and Diop, 1994). To put this number in perspective, during the 2012–2013 vaccination campaign the objective was to vaccinate 50% of the small ruminants against PPR but only 20% were actually vaccinated. During the 2010–2011 campaign, the VACNADA project successfully achieved vaccination coverage of 86% in the St-Louis region (northern Senegal), to be compared with the national average of 14%.

3. Results

The results are summarized in Table 3. The average resource requirements for undertaking 7.9 million vaccines against PPR ranged between USD 1.5 million and 2.7 million, depending on the scenario applied. Scenario A was characterized by an average team productivity of 981 vaccinated animals per day, which lead to a total cost of USD 0.20 per sheep and goat (95% confidence interval (CI): 0.18, 0.21). Results for scenario B were similar, with a slightly lower productivity (943 vaccinated animals per team per day) and the same cost per vaccinated animal (mean cost: USD 0.20 per animal; 95% CI: 0.18, 0.21). Average team productivity for scenario C was 343 vaccinated animals per day, with an average total cost per vaccinated animal of USD 0.33 (95% CI: 0.24, 0.52). Finally, scenario D was characterized by an average team productivity of 331, with an average total cost of USD 0.34 per vaccinated animal (95% CI: 0.24, 0.54).

The resource requirements for the purchase of vaccines and injection supplies represented 66% of the total cost for scenarios A and B, while for the other two scenarios this proportion was slightly lower than 40%. The main difference came from the resources required to cover the staff costs: this cost category represented less than 30% of the total costs for scenarios A and B and more than 50% for scenarios C and D (Fig. 1).

4. Discussion

The average cost per vaccinated animal ranged from USD 0.20 to 0.34, depending on the scenario. The 95% confidence intervals of the cost per vaccinated animal were USD [0.18, 0.21] and USD [0.24, 0.54] for the scenario with the highest (A) and lowest (D) productivity, respectively. Some of these figures are consistent with the USD [0.27, 0.32] range used for the global strategy for the control and eradication of PPR (OIE and FAO, 2015). In Nigeria, characterized by a smaller share of small ruminants located in pastoral zones (68%) compared to Senegal (87%), the cost of vaccinating 80% of the small ruminant population was estimated to be NGN 2572 million (USD 12.922 million), i.e. USD 0.23 per animal vaccinated (Fadiga et al., 2013).

The similarity of the vaccination costs obtained with the VacciCost tool using different percentage reductions in productivity for small flocks, either in high (USD 0.20 in scenario A and B) or low (USD 0.33 and USD 0.34 in scenario C and D respectively) productivity scenarios, shows that this factor had little effect on the estimated cost of vaccination per animal. Indeed, in Senegal the population of small ruminants in mixed systems was less than 15% of the total small ruminant population; therefore this percentage reduction in productivity had negligible to little influence on the results.

In contrast, team productivity had a large effect (difference of USD 0.10 per animal, between scenario A/B and C/D) on the "Personnel" cost component, which captures the labor costs related to vaccination teams. To put in perspective the productivity estimates used in this analysis, we can compute the corresponding number of animals vaccinated per minute. The most likely vaccination team's productivities in pastoral systems were 1000 (scenarios A and B) and 316 (scenarios C and D) animals per day (8 consecutive hours), i.e., 2.1 and 0.7 animals per minute respectively. Taking into account the time spent in transportation, gathering, sorting, and handling the animals, and the fact that at the end of the campaign, the animals to vaccinate are more difficult to reach, the average productivity figures used in scenarios A and B may look optimistic. Overestimating teams' productivity may lead to underestimate vaccination costs. Given the importance of this parameter on the cost, and the uncertainty on its estimates, it is therefore recommended that realistic estimates are carefully chosen, i.e. a productivity that the teams are certain to achieve. If data are not available or updates are needed, it is recommended that systematic records of the teams' daily productivity are kept from the beginning of the campaign. These records can be contrasted with the productivity values used to calibrate the tool to correct the final cost estimates.

A wide range of situations exists in other countries, thus possibly influencing the values of those two parameters (team productivity and percentage reduction in productivity for small flocks). Therefore, the flexibility of VacciCost to consider different production systems with different vaccination productivity is an important feature.

The results obtained during the VACNADA project showed that PPR vaccination campaigns in northern Senegal can be successful (vaccination coverage > 80%) when sufficient financial resources are available, even though vaccination coverage levels used to be historically low in this region (< 35%). This is an evidence that the capacities of Senegalese Veterinary Services are well developed and that the main constraint for reaching high levels of immunization is the lack of resources. Given the success of this project, the amount of resources dedicated to social mobilization in this analysis was proportional to the investment observed in the VACNADA project (USD 425 per team). In Senegal, these resources were used to produce and distribute t-shirts, posters and leaflets, and to pay for a communication team in charge of promoting the campaign before the arrival of the vaccination team. This effort may have contributed to the significant increase in the vaccination coverage experienced that year.

A training session (8 h of effective training) was considered for all agents involved in the vaccination campaign. It would be useful to study the effect of varying the amount of training on teams' productivity and optimize the resources invested in training. The share of total costs represented by training was small in all scenarios (~1%). Therefore, increasing training may be a cost-effective strategy as long as it results in a satisfactory increased level of vaccination productivity. The cost of increasing the duration of the training should also be taken into consideration in the design of the training program, after consultation with experts in training engineering, communication, veterinary public health, etc. If such expertise is not available in the country, external expertise (supranational animal health networks or international organizations) should be considered.

Two exogenous factors pushed down the resource requirements in this analysis.

- Firstly, prices and wages collected were all in CFA Francs (XOF). Since the exchange rate used for the whole analysis is the one observed at the end of 2015 (i.e. 1 XOF = 0.001655 USD), the depreciation experienced by the XOF against the USD (14% in 2014 and 11% in 2015) made costs expressed in 2015 USD 26% lower than if they had been estimated in 2013.
- Secondly, transportation costs were impacted by fuel prices. In June 2014, the barrel of WTI crude oil was > USD 100, whereas at the end of 2015, it was < USD 40. This marked drop in oil price was partially reflected in retail fuel prices: transportation costs

Table 3
Scenarios and results obtained using VacciCost (costs in USD).

	Scenarios A	B	C	D
Productivity (PERT distribution)				
Best-case	1500	1500	795	795
Most likely	1000	1000	316	316
Worst-case	800	800	100	100
Percentage reduction in productivity for mixed systems	50%	70%	50%	70%
Average teams' productivity[a]	981	943	343	331
Total operational cost of the vaccination campaign (USD)				
95% CI –	1,448,659	1,457,361	1,858,915	1,858,915
Average	1,546,025	1,563,944	2,620,207	2,671,714
95% CI +	1,663,051	1,663,051	4,113,799	4,236,796
Total operational cost per vaccinated animal (USD)				
95% CI –	0.18	0.18	0.24	0.24
Average	0.20	0.20	0.33	0.34
95% CI +	0.21	0.21	0.52	0.54

[a] The average teams' productivity is measured by the average number of animals vaccinated per team per day.

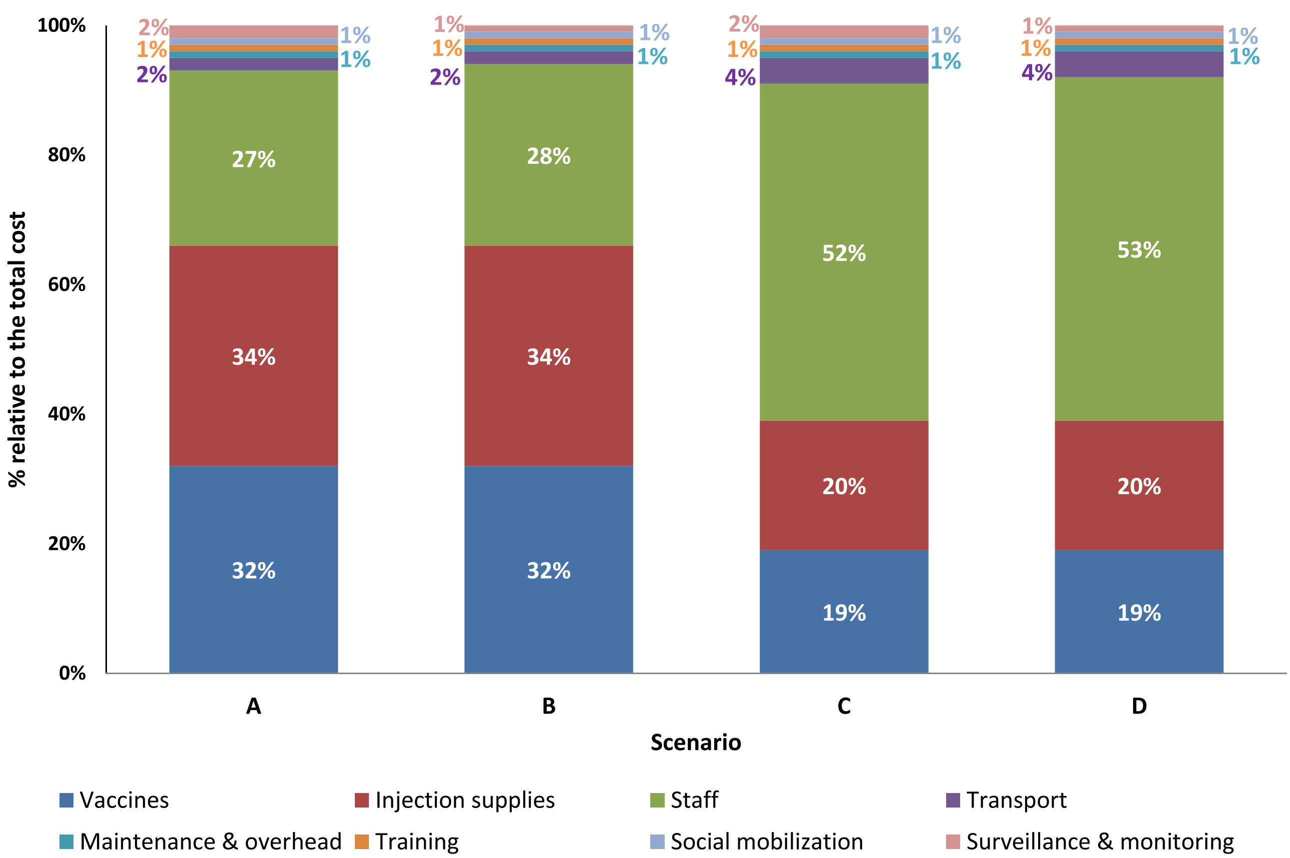

Fig. 1. Distribution of costs by category according to the vaccination team productivity scenario.

would be around 25% higher if the prices of reference had been those observed in 2013.

Moreover, the vehicle maintenance cost is estimated at 15% of the fuel cost. This estimate captures the fact that the cost of maintaining a vehicle increases with its utilization. However, the percentage of the fuel cost that is used to estimate the cost of maintenance depends on the labor costs of each country, which may differ significantly.

In some cases, farmers are asked to cover part of the vaccination costs, hence decreasing the overall cost of the vaccination campaign for the government. The total amount to be subtracted from the vaccination cost obtained with the VacciCost tool can be easily estimated by multiplying the number of vaccines delivered by the payment due by the farmer for each vaccine. This strategy is frequently adopted to make vaccination campaigns sustainable in the long term.

There is a lack of consistent records regarding transportation costs, productivity, and distances traveled to reach vaccination places from previous vaccination campaigns. Better records are needed to improve data quality that would contribute to improve the confidence in the vaccination cost estimates. The important involvement of private veterinarians makes this estimation more complicated since they would also have to adopt good practices to keep records of the key variables mentioned above, and those data should be shared as well. Since vaccination activities are delegated by mandate, keeping records updated and submitted regularly to the DVS could be established as a requirement for the payment of the vaccination campaign by the government.

Additionally, the surveillance component of this tool provides a rough estimate of the surveillance costs (serological tests and wages paid to the surveillance team to collect the samples). However, since the tool does not incorporate any sampling design, other components relevant to surveillance are not captured. Therefore, users of VacciCost should be careful when considering the surveillance costs, which represents a lower bound (i.e. the true surveillance costs are expected to be equal or higher than those provided by VacciCost). Further efforts to develop a tool dedicated for the assessment of surveillance costs would be useful. If a separate analysis of the surveillance costs were available, its results could be used in combination with VacciCost results to account for surveillance expenses.

While sufficient financial resources are required to implement high coverage vaccination campaigns, other factors may prevent authorities from reaching their objectives. For example, the capacity of the laboratory producing the vaccine must be checked to ensure sufficient and timely vaccine provision. Shortages of vaccines are frequent in developing countries due to lack of equipment or staff; it is one of the main obstacles to reach high immunization coverages. Therefore, involving the laboratory staff in strategic planning meetings needs to be considered.

VacciCost's flexibility to consider different production systems is one of the main attributes of the tool. However, VacciCost was designed to estimate the resource requirements linked to livestock vaccination campaigns, so it is not suitable for wildlife or pets. Different models should be conceptualized to adapt the tool to the vaccination of non-livestock animals.

5. Conclusion

VacciCost was used to estimate the resource requirements of implementing an 80% coverage vaccination campaign against PPR in Senegal. Results show that the productivity of vaccination teams is a crucial parameter: increasing the productivity can lead to significant savings. In the case of Senegal, the percentage reduction in productivity linked to vaccinating animals managed in mixed crop-livestock systems in comparison to pastoral systems has little impact on the results due to the small share of small ruminants raised under mixed crop-livestock systems in the country (15%). Given the importance of the teams' productivity, VacciCost is designed to include the uncertainty around this parameter.

Good records of livestock immunization campaigns would much contribute to the improvement of the accuracy of the resource requirements estimates delivered by VacciCost. Availability of data on the variability of teams' productivity between the beginning (when animals are easy to reach) and the end (when animals are hard to reach) of the vaccination campaign would enrich this analysis.

Optimizing the use of resources is crucial for the Senegalese DVS, which faces severe financial constraints. VacciCost provides them with a systematic approach to estimate the resources required to implement their immunization strategy. In the framework of PPR eradication, VacciCost is useful to prepare national budgets that facilitate the demand for complementary funding to reach the immunization coverage required to achieve eradication.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.prevetmed.2017.05.011

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